Volcanic Risk System (SRV): ASI Pilot Project to Support The Monitoring of Volcanic Risk In Italy by Means of EO Data

Maria Fabrizia Buongiorno, Massimo Musacchio
Istituto Nazionale di Geofisica e Vulcanologia
Via di Vigna Murata 605, 00143
Rome, Italy
buongiorno@ingv.it, musacchio@ingv.it

Simona Zoffoli
Agenzia Spaziale Italia
Viale Liegi 26, 00198
Rome, Italy

Chiara Cardaci
Dipartimento della Protezione Civile
Via Vitorchiano, 2 00189
Rome, Italy

Eugenio Sansosti
CNR- Istituto per il Rilevamento Elettromagnetico dell'Ambiente
Via Diocleziano 328, 80124
Naples, Italy

Stefano Vignoli
Advanced Computer System S.p.A.
Via della Bufalotta 378, 00139
Rome, Italy

Angelo Amodio
Galileian Plus S.r.L.
Via Tiburtina 755,00159
Rome, Italy

Sergio Pugnaghi, Sergio Teggi
Università degli Studi di Modena e Reggio Emilia
Via Vignolese
Modena, Italy

Giuseppe Puglisi
Istituto Nazionale di Geofisica e Vulcanologia, INGV-CT
Piazza Roma 2
Catania, Italy

Sven Borgstrom
Nazionale di Geofisica e Vulcanologia, INGV-OV
Via Diocleziano 328
Naples, Italy

Abstract— **The ASI-SRV(Sistema Rischio Vulcanico) project started at the beginning of the 2007 is funded by the Italian Space Agency (ASI) in the frame of the National Space Plan 2003-2005 under the Earth Observations section for natural risks management. Coordinated by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), which is responsible at national level for the volcanic monitoring, the project has as main objective to develop a pre-operative system based on EO data and ground measurements integration to support the volcanic risk monitoring of the Italian Civil Protection Department. The project philosophy is to implement specific modules which allow to process, store and visualize through Web GIS tools EO derived parameters considering three activity phases: 1) knowledge and prevention; 2) crisis; 3) post crisis. In order to combine effectively the EO data and the ground networks measurements the system will implement a multi-parametric analysis tool, which represents and unique tool to analyze contemporaneously a large data set of data in "near real time". The SRV project will be tested his operational capabilities on three Italian Volcanoes: Etna,Vesuvio and Campi Flegrei.**

Keywords-component; Remote Sensing, Volcanic Risck

I. INTRODUCTION

The Italian territory presents a large concentration of actives volcano and the increasing of human population and activities located in the vicinity of active volcanoes has determined to the Italian Civil Protection Department the need to improve the monitoring of these volcanoes. In fact in the volcanic area, the damage to people or buildings is higher if the volcanic event happens in area with high density of population. Moreover the availability of several spatial missions and the possibility to analyse through EO data the main characteristics of volcanic activities have permitted to the Italian Space Agency to introduce the volcanic risk in the National Space Plan 2003-2005. The ASI-SRV project is a pre-operative system and has as main objective the develop an integrate system based to EO data and ground measurements integration to monitor the Italian volcanic activity. Moreover the system considers a number of products, described in the following sections, which may contribute to monitoring different phases of the volcanic risk.

The ASI-SRV system and products have been defined through a detailed User requirement survey that has been

1-4244-2547-1/08/$20.00 ©2008 IEEE

started in the Feasibility Study, funded by ASI in 2004 and integrated with information acquired in other project such as FP6-PREVIEW (2005-2008).The project has started in January 2007 after a feasibility study with a duration of six months during which the positive results have permitted the realization of this pilot project. ASI-SRV project has a duration of 36 months and it includes together with Istituto Nazionale di Geofisica e Vulcanologia (INGV), coordinator of the project and scientific responsable, other two scientific institutions (CNR-IREA and University of Modena and Reggio Emilia) and two very specialized small companies (Advanced Computer System and Galileian Plus) which have as main objective the transformation of the scientific algorithms into quality controlled procedures and visualization interfaces which uses GIS tools on Web in order to permit an easy access to the end users (DPC)

The development of ASI-SRV system is based on three incremental versions. While the first version has regarded the analysis and the integration of the system modules, the other phases will regard the upgrade of the already integrated modules and the integration of other algorithms. Moreover during all the duration of the project the Research and Development phase will permits to follow the scientific and technological improvements during the three years.

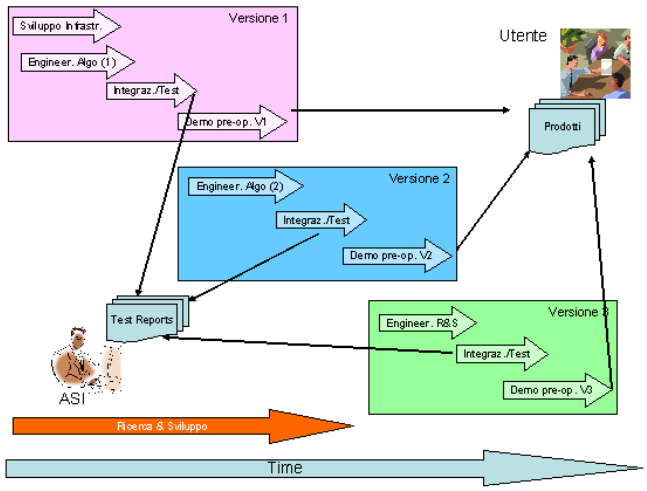

Figure 1 General development schedule requested by ASI for the SRV project, which is based on three incremental versions of the system and a research and development line that permit to follow the scientific and technological improvements during the three years

II. DESCRIPTION OF THE SRV SYSTEM CONCEPT AND MODULES

The efforts to satisfy the requests for operative support expressed by the Italian DPC by means of spaceborne and airborne image data is at the base of all technical design and development of SRV by producing a system concept based on flexible modules which are needed to take into account the new coming space sensors, new processing algorithms and WEB-GIS interfaces considering the national and international scenario in the space technologies. Starting from the modular approach the system should be able to produce all the requested in formation relative to the volcanic activity phases corresponding to the end user operative protocols which are:

1. Knowledge and Prevention (K&P): it identify and measure variations in the state of the volcanic area before the eruption

2. Warning and Crisis (W&C): it support organizations involved in the management of emergency situations in order to activate the planned procedures in the case of a possible emergency in the volcanic areas

3. Post Crisis (PC): it analysis of effects produced by the eruption

For each phase a number of information or products will be generated by SRV according to the end user requests, the system is oriented to produce maps, plots that could be visualized on GIS system and integrated with information acquired by the ground networks that are loaded in the system from the volcanic observatories through automatic protocols or manually by means of human operators . The table 1 show the product selected for each phase.

TABLE I. PRODUCTS REQUESTED BY THE ITALIAN DPC DIVIDED FOR EACH PHASE OF THE VOLCANIC

Phase	Products	Test area
Knowledge and prevention	Multiparametric Analysis product	Etna, Vesuvio and Campi Flegrei
	Deformation Map from DinSAR product	Etna, Vesuvio and Campi Flegrei
	Surface thermal analysis product	Etna, Campi Flegrei
	Volcanic Plumes analysis product	Etna
Warning and Crisis Phase	Deformation Map from InSAR product	Etna, Vesuvio and Campi Flegrei
	Deformation Map from DinSAR product	Etna, Vesuvio and Campi Flegrei
	Surface thermal analysis product	Etna
	Volcanic Plumes analysis product	Etna
Post Crisis Phase	Deformation Map from DinSAR product	Etna, Vesuvio and Campi Flegrei
	Volcanic thickness product	Etna
	Ash and lava distribution map product	Etna

A. Test site selection

The test site interested by the system are Etna, Vesuvio and Campi Flegrei which geographic locations are shown in figure 1. The three test sites have been selected by considering the present state of the volcanic activity and therefore ensure the demonstration of the selected products for each phase (K&P,W&C and PC).

Figure 2 Sites location in Italy and the actual volcanic phenomena associated with each test site

Moreover second parameter used to selected the test areas has been the observability by space of the different volcanic phenomena. Mt. Etna volcano is characterized by an almost persistent volcanic activity, allowing the generation of products related to the sin-eruptive and post-eruptive phase. For this volcano it is possible to provide products also if no eruptive events have occurred, using EO data acquired during the eruptive events in the last years. Vesuvio and Campi Flegrei volcanoes are representative to quiescent phase products analysis, especially regarding the surface deformation map. Moreover the sites selection is compatible with the spatial resolution of EO operative systems and the frequent monitoring with ground networks permits the system to validate and integrate EO products

Figure 3 Test sites selected: on the left the Vesuvio and Campi Flegrei volcanoes viewed by ASTER with DEM overlapped, on the right the Mt. Etna volcano by ASTER.

B. ASI-SRV sub-systems

The selected products after the feasibility study have been transformed to functional requirements of the system. On the base of the functional requirements the system will have the following main sub-systems:

- Data Ingestion
- Central repository
- Processor interface
- Processing modules, divided into:
  - Volcano surveillance and eruption early warning Sub-System (S/S)
  - Sin-eruptive phase support Sub-System S/S
  - Post-eruptive phase support Sub-System S/S
- GIS post-processing module
- Dissemination system
- Utility Functions
  - radiometric calibration,
  - atmospheric correction,
  - DEM coregistration, Ortho correction

During each satellite passage, the system receives data and activate the volcano surveillance and the Early Warning Sub-System including the data from the ground networks. In this way it is able to observe changes in the state of the volcano activity. In case of variation of volcano parameters the system activates the Sin-Eruptive Sub-System. In the SRV pilot project most of the operation are assisted by expert operators at INGV, but the final goal is to achieve information based on a statistical and modeling approach in order to define thresholds that will permit to operate the system mostly automatically. On the end user side of the system the maximum effort is to create customized user interfaces that allowed to use the information sent by the system to support the decision in three phases of the volcanic activity.

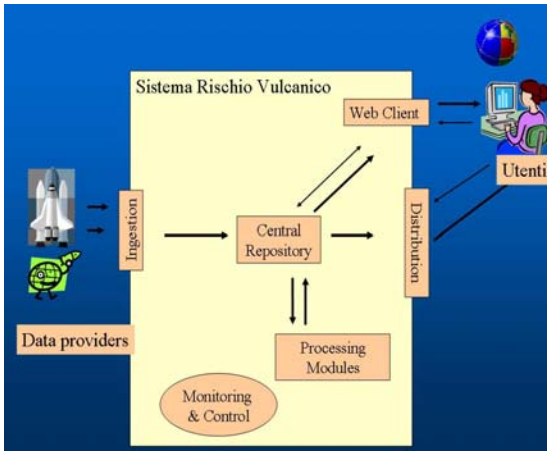

Figure 4 main system Sub-Systems that developed for the SRV project

C. Products feasibility

An important step of the project development regarded the technical and scientific feasibility of the selected products. In fact the technical feasibility depends from the data availability, in the required spectral channel, from satellite revisit time and by the accuracy algorithms and models used in the processing.

The following algorithms have been selected to implement the EO Processing:

TABLE II. LIST OF ASI-SRV ALGORITHMS

Purpose	Algorithms
General purpose	Radiometric calibration module
	DEM co-registration Model
	Atmospheric Correction Tool CIRILLO
SPECIFIC ALGORITHMS	SBAS DINSAR
	Emissivity surface temperature (TES-Q)
	Thermal Analysis
	AOT
	Volcanic Water Vapour
	SO2 content
	Ash loading map
	SAR deformation map (sin eruptive)
	Lava and Ash distribution map
Gis Analysis tools	GIS tool analisys

The algorithms selected for the EO processing modules have been analyzed during the Feasibility study on the basis of the following characteristics:

- Robust with a well proved scientific back ground
- High Adaptability to new space sensor
- Portability into an integrates system
- The algorithms were developed in house (INGV, IREA, University of Modena and R. Emilia) which ensure the possibility to upgrade the procedures and adapt them to SRV system
- Products partially tested in other Projects or INGV surveillance Procedures
- Suitability of the generated products for the selected test sites

As shown in table 3 the deformation maps retrieved by SAR interferometry are based on consolidated techniques [1], which accuracy has been analyzed in the past years. Moreover the selected test sites have well developed GPS network that ensure a suitable validation for the SAR maps produced by the system. Nevertheless the usability of the deformation maps in the Crisis Phase (Sin-eruptive) is restricted by the low revisit time of the current systems. Since the availability of new mission (eg. COSMO-SKYMED) in the next years should improve the revisit time as well as the ground resolution of SAR systems, within the SRV project, prototype procedures for new SAR sensor in X and L band will be developed and tested .

A second very important product area regards the analysis of the surface thermal characteristics, the available algorithms allow to extract information during the K&P phase and during the W&C phase. In the K&P phase the thermal analysis is directed to the identification of temperature variation on volcanic structure which may indicate a change in the volcanic activity state [2]. The feasibility of this product depends from the availability of bands the TIR region and from the accuracy of the atmospheric corrections applied to the images. A major operative limitation for this product is the very low spatial resolution in the TIR channels for space sensors with an high revisit time (>1km pixel). At the moment the only sensor that present good technical characteristics for the K&P is the ASTER sensor (90 m pixel) on NASA satellite TERRA, the lack of future missions with high spatial resolution in the TIR region may prevent an effective support in the early warning phase of volcanic activity by space sensors. The product regarding the Crisis stage is mainly finalized to the estimation of the effusion rate for active lava flows, the algorithms for this product are well consolidated and could be applied to the low spatial resolution space sensors (eg. AVHRR, MODIS, MSG, AATSR) [3]. A third class of products regards the analysis of degassing plumes and eruptive clouds. The analysis of the emitted gas species from degassing plume is usually performed trough ground networks of instruments based on the spectral behaviour of the gas species, although many volcanoes in the world do not have such permanent networks. The SRV system will produce information on the concentration and flux of sulphur dioxide (SO2) [4] water vapour and volcanic aerosol optical thickness [5] by means of ASTER, MODIS and HYPERION data on Etna test site. Experimental algorithms will be tested in the system processing chain for carbon dioxide (CO2) by means of hyperspectral sensors on airborne and spaceborne platforms (eg. Hyperion. AVIRIS). The analysis of ash clouds will be made by means of already consolidated procedures [6, 7, 8] which uses low spatial resolution sensors with an high revisit time (eg. AVHRR, MSG, MODIS). For the Post Crisis phase the required products will be obtained through classification algorithms and spectral analysis operated by the scientific personnel of INGV and introduced in the system repository after the use of modules.

The table 3 shows the results of the algorithm feasibility analysis giving a general index form 5 very high to 1 low which refer to the maturity level of the algorithms. The index also take into account the applicability to the selected geographical area and test site.

TABLE III. SUMMARY OF THE ALGORITHMS ANALYSIS AND MATURITY LEVEL PERFORMED IN THE FEASIBILITY STUDY AND IN THE IN THE REVIEW OF THE USER REQUIREMENT AT THE FIRST PHASE OF THE SRV PROJECT

Products	Data processing			Output		Algorithm Maturity
	Input space data	Auxiliary data	Algorithms	parameter	Trend	LEVEL
Soil deformation	ERS2 ENVISAT RADARSAT	DEM GPS Atmospheric parameters	InSAR	X		4
	ERS2 ENVISAT RADARSAT	DEM GPS Atmospheric parameters	SBAS	X	X	4
	ERS2 ENVISAT RADARSAT	DEM GPS Atmospheric parameters	Permanent Scatterers	X	X	4
Thermal analysis	LANDSAT TM, ASTER, HYPERION AVHRR MODIS	Atmospheric parameters Emissivity Rehology models DEM	Normalization technique Dual Band	X	X	5
Plumes components	ASTER, MODIS MSG	Atmoshoeric parameters emissivity DEM	LUT (SO_2)	X	X	5
			Split Window (SO_2)			5
	HYPERION, MODIS	Atmospheric parameters	CIBR (H_2O)	X	X	4
	QUICKBIRD, ASTER HYPERION MODIS, MERIS	Atmospheric parameters surface spectral reflectance DEM	AOT	X	X	4
Eruptive Clouds	AVHRR MSG-SEVIRI MODIS	Atmospheric parameters Ash characteristics	RAT	X		4
			VAFTAD		X	2
			PUFF		X	2
Post Eruptive and Damage evaluation	SPOT, IKONOS LANDSAT, QUICKBIRD ASTER HYPERION MIVIS	Update DEM Spectral libraries for	Classification Spectral Unmixing DTM comparison	X		3
Early Warning	Multiparametric Analysis (temporal EO series, ground and atmospheric measurements)			X	2	

III. DATA PROCUREMENT

EO data acquisition schedule is carefully evaluated since satellite images will be acquired in a variety of different procedures and supports which depend from National Space Agencies and private companies data policy that generally is not optimized for an operative use of the EO data. During the demonstration phase will be very helpful to enlighten the problems found in the data ordering and shipment compared with the requests of the End User.

IV. CONCLUSION

SRV project has finished the development of architectural design of modules and interfaces and it is now ready to proceed with the realization of the first version which will end with validation test and operative demonstrations. The active contribute of the Italian DPC has been very important in order to meet the requirement requested especially regarding the delivery time of the products in the Crisis Phase. In the next months the web site will be organized in order to show the project development and results.

ACKNOWLEDGMENT

This study was supported by Agenzia Spaziale Italiana Progetto Sistema Rischio Vulcanico project (ASI-SRV ref ASI I/091/06/0). Many colleagues have contributed with useful comments, punctual information and in data treatment. Their list would be simply too long but they are not less important for this project and for the Italian research. The major part of the work presented on this paper is realized by temporary researchers the same researchers that could be fired the next June thanks to Italian government

Country without research = Country without future

REFERENCES

[1] Lanari, R., Mora, O., Manunta, M.,. Mallorquí, J. J, Berardino, P., Sansosti, E., "A Small Baseline Approach for Investigating Deformations on Full Resolution Differential SAR Interferograms", IEEE Transactions on Geoscience and Remote Sensing, Vol. 42, No. 7, July 2004.

[2] Realmuto V.J,. "Separating the effects of temperature and emissivity: emissivity spectrum normalization", in Proc. 2nd TIMS Workshop. Pasadena, CA: Jet Propul.Lab., JPL Publication 90-55, 1990

[3] Lombardo, V., Buongiorno, M.F., Merucci, L., Pieri, D.C., "Differences in Landsat TM derived lava flow thermal structure during summit and flank eruption at Mount Etna", Journal of Volcanology and Geothermal Research, 134/1-2:15-34, 2004

[4] Realmuto V.J. , Abrams M.J. Buongiorno M.F., Pieri C.D. "The use of multispectral thermal infrared image data to estimate the sulfur dioxide flux from volcanoes: A case study from Mount Etna, Sicily, July 29, 1986". Journal of Geophysical Research, Vol. 99, N° B1, pp 481-488, 1994

[5] Spinetti C., M.F. Buongiorno, V. Lombardo, and L. Merucci. "Aerosol optical thickness of Mt. Etna volcanic plume retrieved by means of the Airborne Multispectral Imaging Spectrometer MIVIS". Annals of Geophysics Vol. 46 N.2, 2003

[6] Searcy C., Dean K., Stringer B., "PUFF: A Volcanic Ash Tracking and Prediction Model". J. Volc. and Geoth. Res., 80 (1-2), 1-16, 1998

[7] Corradini S., Cervino M., "Aerosol extinction coefficient profile retrieval in the Oxygen A-band considering multiple scattering atmosphere. Test case: SCIAMACHY nadir simulated measurements", Journal of Quantitative Spectroscopy and Radiative Transfer, Vol. 97, pp. 354-380, 2006.

[8] Constantine, EK, GJS Bluth, and WI Rose (1999, in review) TOMS and AVHRR sensors applied to drifting volcanic clouds from the August 1991 eruptions of Cerro Hudson, AGU Monograph on Remote Sensing of Active Volcanism.